Faculty of Engineering

DETERMINATION OF RAINFALL Φ INDEX FOR SELECTED SITES IN UNIMAS CAMPUS

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……………………………………………………… Date……21/4/04……………

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For my beloved father and mother

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ABSTRACT

Rainfall phi index is one of the criteria of soil types which are on this situation, infiltration rate was in constant. It also can be said that this is the minimum rate that can be achieved by some soil types. Actually the main objective is for the purpose of estimating rainfall phi index values which is by using 'double ring infiltrometer' instrument. This instrument is used to determine infiltration rate into soil and then this data will plotted in graph which is against with time. From graph analysis, a constant value from the curve which is parallel with x axis will be obtained and actually this is the value phi index that has to be determined. From experiment that have been done, value of phi index that has been taken as an average value is 0.7 cm/hr which is it was in between silt loam and loam for it soil types. The range of minimum infiltration is between 0.67 cm/hr to 1.3 cm/hr. Anyway, value of phi index that have been documented is small then phi index from design data. This is causes by several errors that occur during experiment.

ABSTRAK

Phi index merupakan suatu ciri jenis tanah iaitu suatu keadaan dimana kadar peresapan air berada di tahap malar. Ianya juga boleh dikatakan kadar peresapan yang minimum yang mampu dicapai oleh suatu jenis tanah. Objektif utama kajian ini adalah untuk menentukan nilai phi index hujan iaitu dengan menggunakan alat 'double ring infiltrometer'. Alat ini digunakan untuk mengetahui kadar peresapan air dalam tanah dan data ini kemudiannya akan diplotkan dengan graf melawan masa bagi mendapatkan garis lengkung. Melalui analisis graf, suatu nilai malar pada lengkung iaitu garis yang selari dengan paksi x akan dapat ditentukan yang mana nilai tersebut ialah nilai phi index yang hendak ditentukan. Hasil ujikaji yang dibuat menunjukkan bahawa nilai phi index yang diperolehi secara purata ialah 0.7 cm/hr yang mana berada di kumpulan tanah jenis kelodak. Kadar peresapan minimumnya ialah berada dalam julat 0.66cm/hr hingga 1.3cm/hr. Bagaimanapun, nilai ini adalah lebih kecil daripada phi index yang diperolehi daripada data ynag sedia ada. Keadaan ini terpaksa diterima kerana berlakunya ralat semasa menjalankan eksperimen.

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Chapter 1

Introduction

1.1 Introduction of infiltration

Infiltration is the entry of water into the ground. The rate and quantity of waters that infiltrates into the ground is a function of soil type, soil moisture, soil permeability, ground and volume of precipitation. The soil types help to identify the number and size of capillaries potential and relative conductivity. Capillary potential is high and conductivity low for low forces usually expressed as centimeters of equivalent water depth. As rainfall, commences on a dry soil, the moisture level must increase before water will move into the soil mass or relative conductivity must increase. A distinct wetting front develops and, as more precipitation infiltrates into the soil, the thickness of the wet zone increase and the potential for infiltrates decreases. It is this infiltration rate as a hydrologic process that is a concern in relation to infiltration storage rate and volume. (Wanielista, 1984)

1.2 Introduction of phi Index

Phi index is the simpler index for infiltration which is assumes that an infiltration rate over time is constant. To calculate Phi, the surface runoff volume is measured and compared to rainfall volume over time. The difference between rainfall volume and runoff volume divided by duration of the storm is the Phi rate (in. /hr). Adjustments to the Phi rate can be made for initial abstraction. (Beaver, 1977)

1.3 Objective

The main objective of this thesis project is to estimate the rainfall phi index of Samarahan district by focusing of soil types around UNIMAS. Specific objective are: -

1. To determine soil type from study area that will be used as a design data for value of phi index. This are also to shows the value phi index for each types of soils.
2. To study about the infiltration equation based on theories written by Horton's.
3. To study relation between infiltration with infiltration capacity.

Chapter 2

Literature Review

2.1 Infiltration background.

In order to know the distribution and movement of water in the ground, it is a good idea to understand the hydrologic cycle. Let's begin the discussion with precipitation. For the purpose of this discussion, precipitation consists of rainfall that enters on the earth. Some rain will be retained by vegetation then temporally stored in surface depressions with almost all of the depression storage infiltrating into the ground. Water stored in depression, water intercepted by vegetation, and water that infiltrates into the soil during the early part of a storm represent the initial losses. Initial losses mean this water does not appear as runoff during a rainfall event. The rain that drops to the upland streams travels to increasingly larger rivers and then to the seas and oceans. The water that infiltrates into the ground may percolate to the water table or travel in the unsaturated zone until it reappears as surface flow. The amount of water stored in the soil determines, in part the amount of the rain that will infiltrate during the next storm event. Water stored in lakes, seas, and oceans evaporates back to atmosphere where it completes the cycle and is available for rainfall. (Wanielista, 1984)

2.2 Methods exist in measuring the infiltration rate

There are 4 existing methods in measuring the infiltration rate: (1) Theoretical, (2) Empirical using curve numbers (CN), (3) water budget and (4) double-ring infiltrometer

2.2.1 Infiltration using theoretical method

Experiment with unsaturated soil media as reported by Todd (1980) and others, showed that velocity of flow through unsaturated media is proportional to hydraulic conductivity (K), pressure head, and volumetric moisture content (θ). The capillary suction (Ψ) plus the depth of percolating water (L_p) add to produce the pressure head (Δh) for flow in the vertical (z) direction through unsaturated media. A solution procedure was first proposed by Green and Ampt (1991). The rate of movement follows Darcy's law and assuming a hydraulic conductivity equals K_s at saturation, the velocity of infiltration, f(t), is: $F(t) = K_s\,(\Delta h\,/\,\Delta z\,) = K_s\,(\,L_p + \Psi\,)\,/\,L_p$.

The infiltrated water is assumes to percolate through the dry soil as a "slug flow." The volume of water ($F(t)$) in the slug is equal to the difference between the saturated moisture content (θ_s) and the initial content (θ_i) times the depth of percolating water (L_p). The border between the slug of percolating water and the unsaturated soil is the wetted front. At the front, there is average capillary suction head Ψ_{av}. Direct measurement for Ψ_{av}, K_s, and θ_s are generally difficult, but Skaggs and Khaleel (1982) outlined some estimation procedures. Substituting into previous equation for L_p as related to F and θ, the following infiltration capacity equation results:

$$f(t) = K_s + (K_s (\theta_s - \theta_i) \Psi_{av}) / F(t) \qquad (2.1)$$

$f(t)$ = Infiltration rate, in/hr

K_s =Saturation conductivity, in/hr

θ_s =Saturation soil water content which is usually less than soil porosity, fraction of total volume.

θ_i =Initial soil water content, fraction of total volume

Ψ_{av} =Average capillary action (in)

$F(t)$ =Volume of infiltration (in) at time t

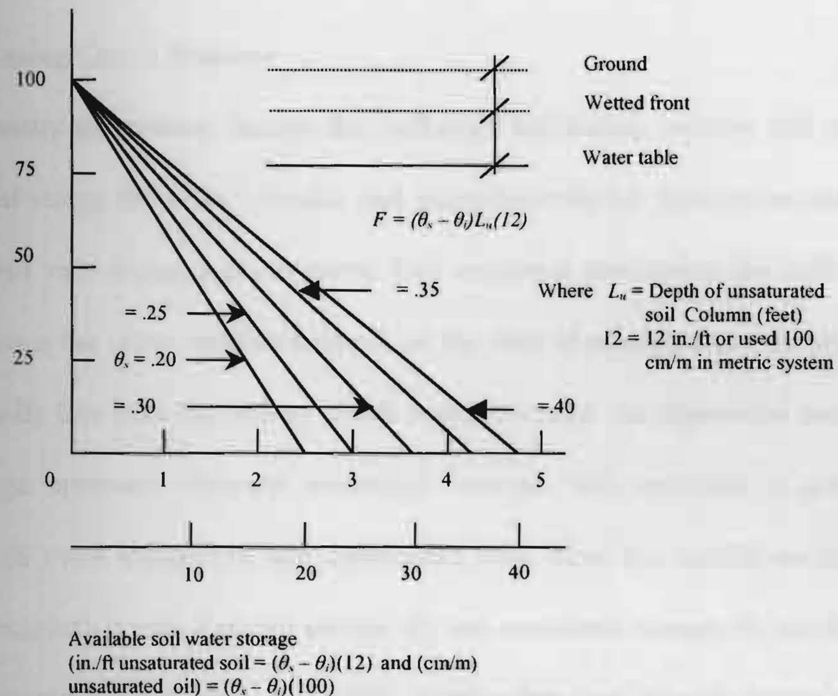

Figure 2.1 Theoretical available soil storage per foot (or meter) of soil for various moisture content and saturated soil water content.

At the moment the ground surface becomes saturated, $F(t) = F_s$. Unit F_s is obtained , the rate of infiltration equals the rainfall rate. The theoretically available soil moisture storage in an unsaturated expressed as the volume of available water storage (depth of water / unit depth of soil), is related to the average water content of soil, and the depth of the soil from the soil surface to the zone of saturation in meters (feet). Figure 2.1 is a graph representation of soil water storage capacity. The relation is plotted for soil having an average soil water content from 20% to 40%. This concept is applicable to homogeneous soils that are not broken by layers of relatively impermeable soils.

2.2.2 Empirical using Curve Number

There are many interrelated factors that influence infiltration volume and rainfall excess. In general terms, these are climatic and watershed related. Infiltration and thus rainfall excess will vary during a storm event. One empirical description for infiltration and rainfall excess is the curve number method. At the start of precipitation, the intensity of rainfall is usually less than the rate at which water is stored. As depression area, and vegetation storage approach ultimate saturation, storage will approach a potential saturation value (S') and infiltration rate approaches zero. Then the rainfall excess rate will equal the precipitation rate. Rainfall excess (R) and watershed storage (S) are derived from precipitation and the soil type. A possible relationship over time is shown on the next figure and rainfall excess (R) is expressed as

$$R = P - S \tag{2.2}$$

Where; R = Rainfall excess

P = Rainfall volume

S = Storage volume on and within the soil (initial abstraction plus infiltration)

At saturation, the rate of rainfall excess is equal to the intensity of precipitation. A proportional relationship can be developed as

$$(S/'S') = (R/P) \tag{2.3}$$

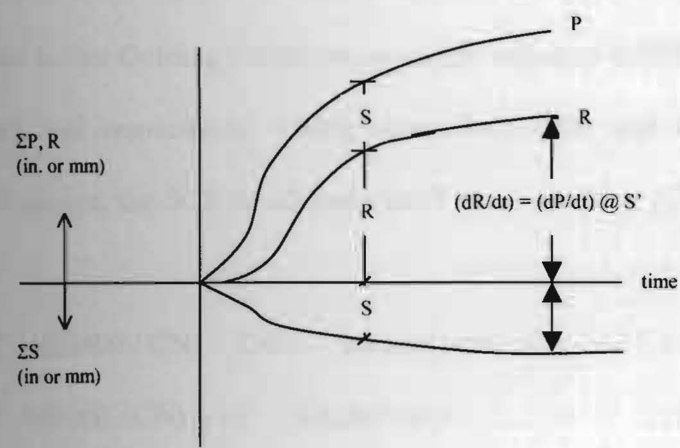

Figure 2.2 Time variability of hydrologic events

Where

S = storage at any time (mm, in.)

S'= storage at saturation (mm, in.)

R = rainfall excess at any time (mm, in.)

P = precipitation at any time (mm, in.)

Since S = P – R, Substituting equation 4.5 yields:

$$(P - R) / S' = R / P$$

$$R = P^2 / (P + S) \text{ for } I_A = 0 \qquad (2.4)$$

Additional work done by the SCS and reported in various publications (Kent, 1973) identified an empirical relationship between the initial abstraction and storage and thus, developed an equation where the initial abstraction was assumed equal to 0.2S'. However, abstraction values for urban areas were shown to be less if the soil types were A or B, and in fact Golding (1986) recommends values of 0.75S' and 0.10S' for A and B type urban soil respectively. Using more then 3000 soil types divided into four hydrologic groups, the SCS developed runoff curve numbers (CN) to estimate S' in next equation:

$$S' = (25400 / CN) - 254 \quad \text{metric (mm) and,}$$

$$S' = (1000 / CN) - 10 \quad \text{English (in.)}$$

And rainfall excess using

$$R = (P - 0.2S')^2 / (P + 0.82S') \quad \text{if } P > 0.25S'$$

And $R = 0$ if $P < 0.25S'$.

2.2.3 Water budget

If infiltration is the only unknown in a water budget and the variable can be easily measured, then a water budget would produce accurate results. But it is usually difficult to measure depression area and interception storage. Water held on the ground forming ponds or water films is referred to as water in depression storage. This water may eventually evaporate and infiltrate depending on ground cover. For small impervious watersheds, 1.0 to 3.0 mm of depression storage is possible. This storage generally decreases as the slope of the watershed increases. For pervious areas, depression storage is greater, ranging from 2.5 mm (0.1in.) for clay to 5 mm (0.2 in.) for sandy soils (Hicks, 1994).

Intercepted water is that which adheres to the surface of plants. In urban areas with 10% folige, Overton and Meadows (1976) estimated that approximately 2.5 mm (0.1 in.) of water is intercepted during the first hour of a storm. For more dense foliage areas, Schomaker (1966) estimated 24% of annual precipitation was intercepted by trees. In areas where the precipitation volume is light (less than 2-3 mm) and there is considerable ground cover, the intercepted water can be significant and potential evaporation high. Thus precipitation volumes reaching the ground may be near zero.

The sum of depression and interception storage is initial abstraction, so named because the initial precipitation will not result in runoff if depression and interception storage are not saturated. Initial abstraction can be measured by knowing the volume of rainfall, runoff and infiltration. Generally, initial abstraction is estimated from field observation included with infiltration estimates or directly measured from the other known quantities. The measurement of runoff and rainfall on near totally impervious areas (parking lots) result in estimating initial abstraction at 1 mm (0.04 in.) (Wanielistaand Shannon, 1977). For dense vegetative areas or flat urban areas, initial abstractions high as 3 or 4 mm (0.12 - 0.16 in.) was used (Wanielista and Shannon, 1977)

2.2.4 Site-specific infiltration (Double ring infiltrometer)

Permeability's and rates of soil infiltration will fluctuate with time and location. Laboratory and field experiment are performed to determine rates. Since permeability's can vary over a range from 10^{-7} cm/ sec for sandy clays to 10^{-2} cm/ sec for loose sands, the designer is confronted with many decisions. Laboratory testing using constant or falling head parameters are of limited value since there is usually too much soil disturbance and the laboratory boundary conditions and gradients are often different from those in the field. Field-testing using borehole or percolation tests is more reliable then laboratory testing for small (< 2000 m^2 areas), but care must be taken to ensure representative testing locations.

For large percolation/ recharge basins or areas, considerably more geotechnical surveying and analysis are necessary. Factors involve in such works are discussed by Walton (1970). A fairly reliable percolation test for use in small retention/detention pond design is the double-ring infiltrometer (Chow, 1964). A double-ring infiltrometer is simply a 55-gal drum as an outer ring with a 10 in. or 12 in. inner ring.

Beaver (1977) formed using an infiltrometer, that infiltration can be represented by Horton's equation (Horton, 1993, 1940). This method gives an expression for time varying infiltration. The Horton equation is shown as equation 2.5 and drawn as shown in Figure 2.3. Also in Figure 2.3 the rate of precipitation is compared to the rate of infiltration. The volume of is under the infiltration curve and the volume of rainfall is the area under the rainfall intensity curve.

$$f(t) = f_c + (f_0 - f_c)e^{-kt} \qquad (2.5)$$

$f(t)$ = Infiltration rate as a function of time cm/hr (in./hr)

f_c = Final, or ultimate, infiltration rate

f_0 = Initial infiltration rate

k = Recession constant (hr-1)

T = time units compatible with k